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Simulation of stress-strain state at the boundaries of a bimetallic composite to determine tear-off resistance

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Abstract. Simulation modeling of the deformation under mechanical action on the sample workpiece of the steel-aluminum bimetallic composite material with a thin aluminum intermediate layer was performed. The stress-strain state along the boundaries of the joint at which the sample workpiece layering occurs was determined. A series of computational experiments with varying the specific work value of the layering under separation conditions was implemented. The level of stresses, leading to the separation of the bimetallic compound, is estimated using the energy criterion. The dependence of the rupture strength along the ring contour on the specific work value of the layering varied in the range of 0.1-0.2 N/mm was calculated. It was established that for the studied variants of the computational experiment, a rigid stress state with the predominance of normal tensile stresses is implemented in place of the beginning of the layering.

1. Introduction

Currently, layered metal composite materials (LMCM) based on low carbon steels and aluminum alloys, obtained by the method of hot rolling, are increasingly used. In the development of processes and the manufacture of multilayer metals, quality assessment of the compound is carried out by mechanical and in-process testing of the compound samples, as well as metallographic studies of the boundaries of the materials joint. However, the known methods of mechanical, in-process testing and metallographic studies do not always allow assessing the quality of the layers joint, for example, for composites with a thickness of layers or interlayer less than 1 mm.

One of the typical damages to layered materials during deformation is layering along the joint boundary. Therefore, the determination of the strength characteristics of the composite layers interfaces at separation and shear are of practical value to ensure the reliability of the product under operating conditions. Evaluation of strength characteristics depends on many factors, such as the testing design, configuration and sample workpiece size. Different amounts, layers alternation schemes, as well as the thickness of the layers, apply their own characteristics of such materials deformation under the same test conditions. Therefore, identification of fracture patterns at the boundaries of multilayer metallic materials under various types of impact is a rather complex task, the solution of which is still far from completion.

To describe the processes of formation and growth of cracks, as well as layering, the use of the fracture mechanics methodology has become common practice in the LMCM. At present, an approach



based on the calculation of the layering specific work [1] is used to study the behavior of composite structures and determine the conditions for initialization and growth of the layering. This approach is usually applied using the finite element method.

The purpose of the study is determining using computational experiment method the features of the stress-strain state at the interlayer boundaries of the steel-aluminum composite material with a thin interlayer to determine the rupture strength along the ring contour.

2. Method of solution

In computational experiments, the model of the sample, which is shown in Figure 1, was used to study the deformation processes in layered composites. The sample workpiece is an axisymmetric body mounted on a support consisting of three plates with a cut-out for the punch. The thicknesses of layers 1, 2 and 3 were as follows: 7.2 mm, 0.6 mm and 7.2 mm, respectively. In layers 1 and 2 there is a cylindrical hole for a punch 4 with a diameter of 3 mm. Simulation modeling was performed using the finite element method. To implement the deformation, the sample workpiece was subjected to the movement of the punch 4 with fixation of the force F . For each layer, an elastoplastic model of material with nonlinear hardening specified in a tabular form is used. The material model for the top plate corresponds to the properties of 12H18N10T steel; the properties of the AD1 aluminum alloy were set for the intermediate layer; the properties of AMg6 alloy were set for the lower plate. The properties of materials were adopted from the paper [2].

To determine the conditions for the initialization of the layering formation and growth process, a criterion using the energy condition was applied [3], according to which the elastic energy G release rate must be equal to or higher than the layering specific work under the conditions of G_{IC} separation. Comparative analysis of the stress-strain state was performed at G_{IC} values of 0.1, 0.15 and 0.2 N/mm. The stress-strain state was estimated at the interlayer boundaries, at which layering began to develop.

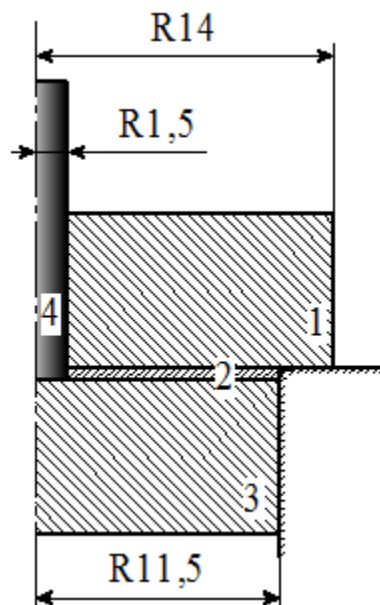


Figure 1. The geometric model sample workpiece: 1 – plate of steel 12H18N10T; 2 – intermediate layer of aluminum alloy AD1; 3 – plate of alloy AMg6; 4 – punch

3. Results and discussion

It was established that the initialization of the layering process and its growth occur almost simultaneously. The layering extends from the center of the sample workpiece to its periphery. Figure 2 shows the dependence of the layers adhesion stress on the movement of the punch. The layers adhesion stress was calculated as the ratio of the force on the punch to the contact area at the interlayer boundary,

which is 413.5 mm^2 . It was shown that with this sample workpiece configuration at G_{IC} equal to 0.2 N/mm , a punch movement of 10 mm is required to carry out the separation. This leads to significant deformation of the lower layer. In this case, the layers adhesion stress increases slightly, reaching a maximum value of 26 MPa . In the studied sample workpiece, plastic deformation is concentrated in the intermediate layer near the punch. Depending on the G_{IC} values used in the calculations, the degree of plastic deformation until the moment of separation in the interlayer is 0.013 , 0.017 and 0.02 , respectively, I was established that for all variants of the calculation, the stress state indicator (the ratio of the average normal stress to the intensity of tangential stresses) at the place of layering is $k = 0.58$, and the Lode-Nadai index $\mu_\sigma = +1$. These values remain almost unchanged during the process of deformation. Such indicators characterize a fairly rigid stress state with the predominance of normal tensile stresses.

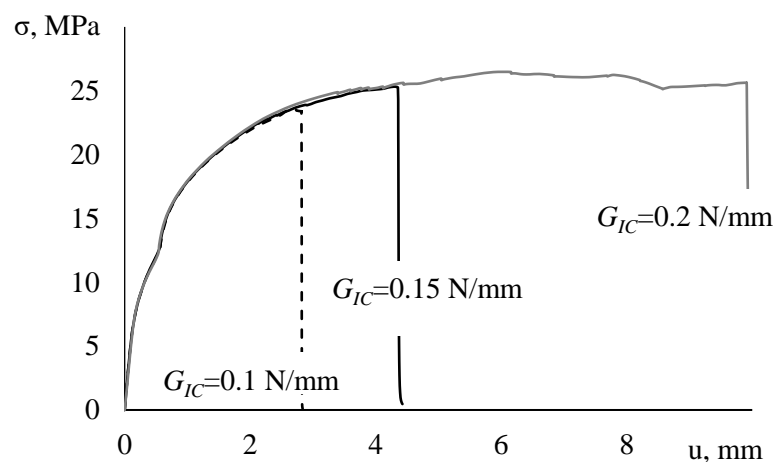


Figure 2. The dependence of the layers adhesion stress σ on the movement of the punch u

4. Conclusion

A series of computational experiments were carried out in order to study the processes of deformation in layered metal composites and predict their layering under mechanical action. It was calculated that to ensure complete separation according to the energy criterion for the sample workpiece of this configuration, the layering specific work under the conditions of separation G_{IC} should not exceed a value of 0.2 N/mm . It is shown that crack initiation and growth occurs at the boundary of the aluminum interlayer near the concentration of maximum stress intensity values, in the region with the predominance of normal tensile stresses. Despite the fact that the approach implements a model of brittle fracture, that is, the initiation of layering and its growth occur almost simultaneously, plastic strains occur and develop in the interlayer. For the sample workpiece configuration used, the increase in the layering specific work under the conditions of separation G_{IC} has a significant effect on the deformation in the lower layer. At the same time, a significant increase in the force on the punch, and, accordingly, in the rupture strength does not occur in the studied range of G_{IC} .

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